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Research Paper

Effect of biochar levels and integrated nutrient-management practices on agro-physiological performance and productivity of maize (*Zea mays*)

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ABSTRACT

The experiment was laid out in a factorial randomized block design, during the pre-rainy season of 2018 and 2019 at ICAR Research Complex for North Eastern Hills Region, Umiam, Meghalaya, to study the effect of biochar and integrated nutrient management practices on agro-physiological performance and productivity of maize (*Zea mays* L.). comprising 4 treatments, viz. B_1, (Control); B_2, (5 t/ha biochar); B_3, (10 t/ha biochar); B_4, (15 t/ha biochar) in factor A and factor B having 3 integrated nutrient-management (INM) practices NM_1 [(100% recommended, viz. dose of nitrogen (RDN)]; NM_2 [(75% RDN + 25% FYM)]; NM_3 (50% RDN + 50% FYM), in 3 replications. The results showed that an application of biochar @ 15 t/ha resulted in significantly higher plant height (171.4 and 177.1 cm) and dry-matter accumulation (393.1 and 401.5 g/plant) at harvesting stage, leaf area index (LAI) at 60 days after sowing (4.78 and 4.85) and 90 days after sowing (DAS) (5.45 and 5.52), crop-growth rate (CGR) at 30–60 days after sowing (37.3 and 38 g/m^2/day). This treatment also resulted in significantly higher kernel/cob (267.8 and 275.8), rows/cob (20.7 and 21), kernel/row (19.9 and 21.8), kernel (4.43 and 4.49 t/ha) and stover yield (7.02 and 7.07 t/ha), total nitrogen uptake (141.8 and 140.4 kg/ha), total phosphorus uptake (23.8 and 23.6 kg/ha), total potassium uptake (115.9 and 114 kg/ha) and gross returns (102,664 and 104,023 ₹/ha) in 2018 and 2019 as compared to the other treatments. In the case of INM practices, significantly higher plant height (161.6 cm) and dry-matter accumulation at the harvesting stage (367.2 g/plant), leaf area index at 60 days after sowing (4.60) and 90 days after sowing (5.23), crop growth rate (34 g/m^2/day) at 30–60 days after sowing, kernels/cob (234.9), rows/cob (18.4), kernel/row (19.0), kernel (4.15 t/ha) and stover yield (6.56 t/ha), total nitrogen uptake (125.6 kg/ha), total phosphorus uptake (21.4 kg/ha), total potassium uptake (100.7 kg/ha) and gross return (95,931 ₹/ha) were noticed under 75% RDN + 25% FYM during the first year, while during the second year significantly higher plant height (167.6 cm) and dry-matter accumulation at harvesting stage (375.7 g/plant), leaf area index at 60 days after sowing (4.69) and 90 days after sowing (5.31), crop growth rate (35.2 g/m^2/day) at 30–60 days after sowing, kernels/cob (241.0), rows/cob (18.7), kernel/row (20.8), kernel (4.25 t/ha) and stover yield (6.63 t/ha), total nitrogen uptake (125.1 kg/ha), total phosphorus uptake (21.5 kg/ha) and total potassium uptake (99.1 kg/ha) were recorded under 50% RDN + 50% FYM than the control, but gross returns (95,931 ₹/ha) were noticed under 75% RDN + 25 FYM. The best alternative choice for maize production in the India Himalayan area or other similar ecoregions may be the use of biochar @ 15 t/ha together with the concomitant application of 50% RDN + 50% FYM.

Key words: Agro physiological performance, Biochar, INM, Maize, Productivity

Maize (*Zea mays* L.) is a versatile and highly productive cereal crop and feeds nearly 30% of the world's food calories to over 4.5 billion people and demand for the grain is predicted to quadruple by 2050. In India maize is grown on 9.2 million ha with a productivity of 2,700 kg/ha (MoAC & FW, 2020–21). Maize is widely used in different sectors as food, feed, and fodder for humans and animals as well as raw material for beverage industries (Kumar *et al.*, 2018). Intensive tillage and indiscriminate use of fertilizers to get a good seed-bed for sowing, better germination and high productivity contribute to declining soil organic matter, and deterioration in the biological and physical health of the soil over the years. In this perspective, biochar and

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integrated nutrient management has drawn considerable attention from researchers, as these have potential to increase resource-use efficiency, productivity, profitability and develop soil health. Biochar application to the degraded infertile/acidic soils improves the soil condition (Xia *et al*., 2020). An increase in crop productivity, profitability, energy-use efficiency and quality with the application of biochar plus amendments has been reported (Walia and Patidar, 2021). The use of biochar in conjunction with nitrogen fertilizer had a greater favourable impacts on crop nutrient-use efficiency (NUE) and soil quality. Biochar impacts nitrogen fixation, mineralization, and immobilization (Aller *et al*., 2019). It may greatly improve the cation-exchange capacity of the soil, promote soil fertility, and help to crop growth owing to its unique structure (Sashi *et al*., 2018). Because of high porosity, biochar can absorb nitrogen and affect physico-chemical and biological features of soil, such as soil structure, porosity, *p*H, nutrient availability, microbial population, and enzyme activity (Zhang *et al*., 2018).

Integrated nutrient management (INM) significantly increases crop productivity, quality and profitability (Parkinson, 2013). The INM enhances maize grain yield by more than 92% and rainwater usage efficiency (Hussain *et al*., 2019). Hence, present study was conducted to assess the effect of biochar levels and INM practices on agro-physiological performance, nutrient acquisition, productivity and profitability of maize.

MATERIALS AND METHODS

The field experiment was conducted during pre-rainy (*kharif*) seasons of 2018 and 2019 at Research Farm of the ICAR Research Complex for North-Eastern Hills (NEH) Region, Umiam (25° 41’ N and 91° 54’ E 980 m above mean sea-level), Meghalaya. Research farm has a semi-arid and sub-tropical climate with hot dry summer and severe cold winter. August was the hottest month of the year where the maximum temperature remained 29–30°C, while December being the coldest the mean minimum temperature was as low as 8.5°C. The mean annual rainfall was about 1,883 mm, of which nearly 80% was received during the monsoon period from July to September and the rest during the period between October and May. The soil of experimental was clay loam having bulk density (1.16 Mg/m^3), *p*H 5.46, electrical conductivity (0.23 dS/m), high organic carbon (1.12%), low available N (202 kg/ha), medium available P (16.2 kg/ha) and high available K (134 kg/ha). The experiment was laid out in a factorial randomized block design (FRBD), comprising 4 treatments, viz. B_1 (Control); B_2 (5 t/ha biochar); B_3 (10 t/ha biochar); B_4 (15 t/ha biochar) as factor A and factor B having 3 integrated nutrient-management (INM) practices like NM_1 [100% recommended dose of nitrogen (RDN)]; NM_2 (75% RDN + 25% FYM); NM_3 (50% RDN + 50% FYM) with 3 replications The nutrients were supplied through farmyard manure (containing 0.47% N, 0.22% P and 0.49% K approx.), biochar (containing 5.5 g/kg N, 0.99 g/kg P and 3.50 g/kg K), urea, diammonium phosphate and muriate of potash respectively. The treatment-wise full dose of P and K and half the dose of N were applied basal at sowing and the remaining N was top-dressed 35 days after sowing. Maize cultivar ‘DA 61 A’ was sown in the second week of February at 50 cm × 20 cm crop geometry with a seed rate of 22 kg/ha and harvested in the second week of July. The crop was raised with the recommended package of practices. Observations were recorded on plant height, dry-matter accumulation, leaf area index, crop-growth rate, kernels/cob, kernels/row, test weight, kernel and stover yield. Plant height at 90 days after sowing and harvesting stage was recorded on 5 random plants from sampling rows and measured from the ground to the top leaf of plant by centimeter scale and average was calculated. 5 plants per plot were cut from the ground level from sampling row at 60, 90 and 120 days after sowing. These plants were first air-dried for 2–3 days and then oven-dried at 60–65°C for 48 hours and dry weight was recorded (g/plant). The leaf area of 5 plants was measured with the help of leaf area meter (Model LI-COR-3100) and the leaf area index/plant was calculated. The mean crop-growth rate was worked out as per Watson *et al.* (1952).

The data collected for different parameters were subjected to statistical analysis by following the procedure of ANOVA (SAS Software packages, SAS EG 4.3). Significance of difference between means was tested through ‘F’ test and the least significant difference (LSD) was worked out where variance ratio was found significant for treatment effect. The treatment effects were tested at 5% probability level for their significance.

RESULTS AND DISCUSSION

Agro-physiological performance

Plant height, dry-matter accumulation, leaf-area index and mean crop-growth rate of maize were significantly influenced by biochar levels and integrated nutrient management practices during both the years (Table 1). However, significantly maximum plant height and dry-matter accumulation at the harvesting stage were recorded under biochar @ 15 t/ha as compared to the remaining treatments (Table 1). Significantly maximum leaf-area index at 60 DAS and 90 DAS was registered with the application of biochar @ 15 t/ha. Significantly highest mean crop-growth rate at 30–60 DAS was recorded under the biochar @ 15 t/ha as compared to other biochar treatments. Application of biochar increased the plant height and dry-matter

Table 1. Effect of biochar levels and integrated nutrient-management practices on growth and agro-physiological performance of maize crop

Treatment	Plant height (cm)		Dry-matter accumulation/plant (g/plant)		Leaf-area index				Crop-growth rate (g/m^2/day)	
	At harvesting		At harvesting		60 DAS		90 DAS		30–60 DAS	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Biochar										
Control	127.4	135.6	305.4	308.8	3.75	3.81	4.62	4.69	28.9	29.3
Biochar @ 5 t/ha	150.2	157.0	359.2	366.8	4.30	4.38	5.08	5.15	30.7	32.7
Biochar @ 10 t/ha	162.1	167.9	383.2	391.1	4.48	4.58	5.30	5.39	33.4	34.8
Biochar @ 15 t/ha	171.4	177.1	393.1	401.5	4.78	4.85	5.45	5.52	37.3	38.0
SEm±	2.01	2.40	2.10	3.30	0.02	0.03	0.02	0.02	0.61	0.72
CD (P=0.05)	8.32	6.11	6.58	9.55	0.07	0.10	0.07	0.06	2.10	2.55
Integrated nutrient-management										
100% RDN	152.7	151.1	360.3	359.3	4.44	4.02	5.15	5.04	32.4	32.1
75% RDN + 25% FYM	161.6	159.5	367.2	366.1	4.60	4.50	5.23	5.21	34.0	33.7
50% RDN + 50% FYM	144.0	167.6	353.1	375.7	3.95	4.69	4.96	5.31	31.2	35.2
SEm±	2.74	2.22	2.37	2.99	0.02	0.02	0.01	0.02	0.64	0.83
CD (P=0.05)	7.20	6.29	6.69	8.27	0.07	0.06	0.04	0.07	1.82	2.21

DAS, days after sowing; FYM, farm yard manure; RDN, recommended dose of nitrogen

accumulation because it provided adequate nutrients for a longer period which attributed to a better nutritional environment for plant growth at active vegetative stages as a result of enhancement in cell multiplication, cell elongation and cell expression in the plant body (Kumar *et al*., 2018). Crop-growth rate (CGR) is a function of dry-matter accumulation which is reflected in LAI as higher fertility levels also maintain higher LAI, though both the CGR and LAI decreased with the advancement of crop age (Sashi *et al*., 2018).

At harvesting stage, a significantly maximum plant height and dry-matter accumulation were recorded under 75% RDN + 25% FYM as compared to the remaining treatments in the first year (Table 1). However, in the second-year the highest plant height and dry-matter accumulation were observed under 50% RDN + 50% FYM which was significantly higher than 75% RDN + 25% FYM and 100% RDN. The maximum leaf-area index was noticed at 60 DAS and 90 DAS under 75% RDN + 25% FYM which was significantly higher than the other treatments in the first year, while the second year significantly maximum leaf-area index at 60 DAS and 90 DAS was recorded in 50% RDN + 50% FYM which was significantly higher than the remaining treatments (Table 1). Similarly, significantly highest mean crop-growth rate at 30–60 DAS was observed under 75% RDN + 25% FYM as compared to the other treatments during the first year. As compared to the remaining treatments during the second year, significantly maximum value of mean crop-growth rate at 30-60 DAS was noticed under 50% RDN + 50% FYM. Conjoint application of organic and inorganic sources of nutrients supply the proper amount of nitrogen which is directly involved in the multiplication, elongation and expansion of cells and ultimately produced more plant height, number of leaves/plant, leaf-area index, and dry-matter accumulation, and when the crop reached maturity, shedding of leaves resulted in a reduced mean crop-growth rate (Hussain *et al*., 2019).

Yield attributes and yield

Biochar levels and integrated nutrient-management practices had significant effect on yield attributes and yield of maize during both years except number of cobs/plant (Table 2). Among the different levels of biochar, maximum kernels/cob, rows/cob, kernels/row were found under biochar @ 15 t/ha, being significantly higher than the other treatments during both the years. Across the study year, kernel yield and stover yield of maize varied from 3.53 to 4.49 t/ha and 5.41 to 7.07 t/ha, respectively. Significantly maximum kernel yield (4.43 and 4.49 t/ha) was noticed in the first and second year, respectively, under biochar @ 15 t/ha as compared to the remaining treatments. Across the study year, significantly highest stover yield was recorded under biochar @ 15 t/ha followed by biochar @ 10 t/ha. Application of biochar increased the yield and yield attributes probably owing to increased activity of meristematic tissues of plants at optimum fertility levels, as NPK play a role in cell differentiation, meristematic division and higher translocation of food materials in plants, thereby resulting in higher production of yield attributes and yield (Aller *et al*., 2018).

Among the INM practices, significantly highest kernels/cobs, kernels/row and rows/cob were observed under 75% RDN + 25% FYM as compared to the remaining treatments during the first year. While during the second year the highest number of kernels/row, kernels/cob and rows/cob were found under 50% RDN + 50% FYM which was statistically at par with 75% RDN + 25% FYM. During the first year significantly maximum kernel yield/plant was recorded under 75% RDN + 25% FYM, followed by 100% RDN and 50% RDN + 50% FYM. However, during the second year highest kernel yield/plant (254.5 g) was recorded with the application of 50% RDN + 50% FYM, being at par with 100% RDN and 75% RDN + 25% FYM. However, during the first year significantly maximum kernel yield (4.15 t/ha) was noticed under 75% RDN + 25% FYM, followed by 100% RDN. However, during the second year significantly higher kernel yield (4.25 t/ha) was recorded with the application of 50% RDN + 50% FYM followed by 75% RDN + 25% FYM. Application of 75% RDN + 25% FYM resulted in the highest stover yield (6.56 t/ha) during the first year but it remained at par with the other treatments, while during the second year the maximum stover yield (6.63 t/ha) was registered under 50% RDN + 50% FYM followed by 100% RDN and 75% RDN + 25% FYM. The conjoint application of organic and inorganic sources of nutrients might have resulted in more growth hormones released that helped in optimum fertilization of flowers and increased pollengrain viability and thereby increased kernels/plant (Rubab *et al.,* 2017). The increase in kernel yield under adequate nutrients supply might be ascribed mainly owing to the combined effect of higher plant height, more dry-matter accumulation at different stages, more kernels/cob, rows/cob, kernels/plant and higher kernels weight, which was the result of better translocation of photosynthates from source to sink, and ultimately crop yield was increased (Walia and Patidar, 2021).

Total nutrient uptake by crop

Significantly maximum total nitrogen uptake by the crop was found under biochar @ 15 t/ha during the first and second year. It was followed by application of biochar @ 10 t/ha (Table 3). Significant highest total phosphorus and potassium uptake were registered under biochar @ 15 t/ha during both the years. Significantly maximum total nitrogen and potassium uptake was recorded by application of 75% RDN + 25% FYM, followed by 100% RDN during 2018, while, during 2019 the highest value of total nitrogen and potassium uptake was recorded under 50% RDN + 50% FYM, followed by 75% RDN + 25% FYM. During the 2018 significant higher total phosphorus uptake was noticed under 75% RDN + 25% FYM, while during 2019 the maximum total phosphorus uptake was recorded under 50% RDN + 50% FYM. It was evident from the earlier reports that, the application of biochar and FYM in conjunction with fertilizer had an additional favourable impact on crop nitrogen-use efficiency and soil physical, chemical and biological properties (Xia *et al.,* 2020). Because of its high porosity, biochar can absorb nitrogen (Laird *et al*., 2010) and improve water retention and nutrient availability (Kloss *et al*., 2012).

Economics

Gross returns were significantly higher under biochar @ 15 t/ha than all remaining treatments (Table 3). During first year, the maximum net returns were recorded with biochar @ 5 t/ha being statistically at par with biochar @ 10 t/ha and significantly higher than the other treatments. However, during the second year higher value of net returns was noticed under biochar @ 5 t/ha, being statistically similar to the control but significantly higher than the remaining treatments. A significantly higher benefit: cost ratio was noticed under the control plot as compared to the remaining treatments during both years.

Significantly maximum gross returns were recorded with 75% RDN + 25%, while during the first year maximum gross returns were under 50% RDN + 50% FYM during the second year. The maximum net returns were recorded under 75% RDN + 25% FYM, being statistically superior to rest of the treatments. Similar results with 100% RDN and 50% RDN + 50% FYM during 2018 while the highest net returns during 2019 were registered under 50% RDN + 50% FYM which was statistically at par with 100% RDN and 75% RDN + 25% FYM. Significantly maximum benefit: cost ratio was registered under 100% RDN but it remained statistically at par with 75% RDN + 25% FYM during both the years. Escalated cost of treatments due to additional inclusion of biochar and FYM at varied rates escalated the cost of cultivation. Though corresponding increase in yield was noticed when benefit: cost ratio was analyzed it recorded lower proportion due to marginal return and higher cost of production (Rubina *et al.,* 2018).

Thus, application of biochar @15 t/ha resulted in significantly higher plant height, dry matter, leaf-area index, crop-growth rate, kernels/cob, rows/cob, kernels/plant, kernels and stover yield, total nutrient uptake and gross returns than the other treatments. In case of integrated nutrient-management practices, significantly higher plant height and dry-matter, leaf area index, crop-growth rate, kernels/cob, rows/cob, kernels/plant, kernels and stover yield, total nutrient uptake and gross returns were noticed under 75% RDN + 25% FYM during the first year, while these parameters were significantly higher during the second year under 50% RDN + 50% FYM compared to the control. Thus, using biochar @ 15 t/ha along with the simultaneous application of 50% RDN + 50% FYM is the best alternative option for maize production in the India Himalayan region or other similar ecoregions.

Table 2. Effects of biochar levels and integrated-nutrient-management practices on yield attributes and yield of maize crop

Treatment	Kernels/ cob		Kernels/ row		Rows/ cob		Kernel yield (g/plant)		Test weight (g)		Kernel yield (t/ha)		Stover yield (t/ha)	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Biochar														
Control	193.8	197.8	15.1	16.3	12.7	12.9	206.1	209.6	223.44	224.89	3.53	3.69	5.41	5.48
Biochar @ 5 t/ha	217.2	223.3	17.5	19.7	16.3	16.6	236.6	244.3	233.33	235.00	3.93	4.06	6.49	6.53
Biochar @ 10 t/ha	242.6	250.4	18.7	20.5	18.6	18.8	250.4	254.7	237.33	241.11	4.14	4.21	6.79	6.99
Biochar @ 15 t/ha	267.8	275.8	19.9	21.8	20.7	21.0	270.6	276.8	244.00	246.00	4.43	4.49	7.02	7.07
SEm±	0.97	12.10	0.18	0.34	0.20	0.25	11.5	10.5	2.85	2.93	0.07	0.08	0.16	0.15
CD (P=0.05)	4.02	35.50	0.77	1.40	0.85	1.03	36.4	26.5	NS	NS	0.20	0.26	0.45	0.42
Integrated nutrient-management														
100% RDN	230.5	232.1	18.2	18.3	17.2	15.9	240.8	238.3	234.17	232.50	4.01	3.98	6.41	6.40
75% RDN + 25% FYM	234.9	237.5	19.0	19.6	18.4	17.4	249.4	246.1	239.33	236.00	4.15	4.10	6.56	6.52
50% RDN + 50% FYM	225.8	241.0	16.1	20.8	15.7	18.7	232.6	254.5	230.08	241.75	3.87	4.25	6.31	6.63
SEm±	0.84	10.9	0.16	0.29	0.18	0.21	9.34	8.37	2.79	2.81	0.06	0.07	0.14	0.16
CD (P=0.05)	3.48	26.9	0.66	1.21	0.73	0.89	25.5	21.6	NS	NS	0.19	0.21	0.40	0.48

DAS, days after sowing; FYM, farm yard manure; RDN, recommended dose of nitrogen

Table 3. Effect of biochar and integrated nutrient-management on total nutrient uptake and economics of maize crop

Treatment	Nitrogen uptake (kg/ha)		Phosphorus uptake (kg/ha)		Potassium uptake (kg/ha)		Gross returns (₹/ha)		Net returns (₹/ha)		Benefit: cost ratio	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Biochar												
Control	87.0	88.0	14.4	14.8	70.1	69.9	81,007	84,248	45,071	47,562	1.26	1.30
Biochar @ 5 t/ha	113.2	113.5	17.9	18.2	92.2	91.4	91,529	94,259	48,093	50,073	1.11	1.14
Biochar @ 10 t/ha	128.3	129.1	20.1	20.3	103.5	104.5	96,389	98,084	45,453	46,399	0.90	0.90
Biochar @ 15 t/ha	141.8	140.4	23.8	23.6	115.9	114.0	102,664	104,023	44,229	44,838	0.76	0.76
SEm±	3.61	4.75	0.47	0.39	2.79	2.90	677.0	760.6	677.0	760.6	0.01	0.02
CD (P=0.05)	10.5	12.0	1.32	1.42	7.29	7.74	2,808.4	3,155.2	2,808.4	3155.2	0.06	0.07
Integrated nutrient-management												
100% RDN	117.7	110.5	18.7	17.3	95.5	90.4	92,957	95,021	48,384	49,698	1.12	1.14
75% RDN + 25% FYM	125.6	117.8	21.4	18.8	100.7	95.4	95,931	98,186	48,745	50,250	1.07	1.09
50% RDN + 50% FYM	109.5	125.1	17.1	21.5	90.2	99.1	89,804	92,254	40,006	41,706	0.83	0.85
SEm±	3.53	4.63	0.44	0.35	2.69	2.78	586.3	6,58.7	586.3	658.7	0.01	0.01
CD (P=0.05)	9.20	11.6	1.30	1.34	7.85	7.24	2,432.1	2,732.5	2,432.1	2,732.5	0.05	0.06

DAS, days after sowing; FYM, farm yard manure; RDN, recommended dose of nitrogen

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